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Interoperability Strategic Vision

A GMLC WHITE PAPER

MARCH 2018

This Interoperability Strategic Vision whitepaper promotes a common understanding of the meaning and characteristics of electric grid interoperability and provides a strategy to advance the state of interoperability as applied to integration challenges facing grid modernization. This paper is important to those involved in integrating smart technology in the electric power sector, particularly those participating in projects where the integration requires agreements on information and communications decisions with others and where integration needs to occur easily and reliably. The objectives of simplifying integration are critical to such projects' success and requires the alignment of all stakeholders on concepts, standards, and policies that can only be achieved through participation and buy-in.

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SUMMARY

Historically, social progress occurs when many entities communicate, share information, and together create something that no individual entity could do alone. As machines and automated systems are integrated into society, interoperability is the necessary capability of systems and devices to provide and receive services and information between each other, and to use the services and information exchanged to operate effectively together in predictable ways without significant user intervention. When people talk about the “modern” or “smart” grid, the ease of integration that delivers interoperability is a necessary foundation of that concept.

This Interoperability Strategic Vision whitepaper[1] aims to promote a common understanding of the meaning and characteristics of interoperability and to provide a strategy to advance the state of interoperability as applied to integration challenges facing grid modernization. This includes addressing the ease and reliability of integrating devices and systems and the discipline to improve the process of successfully integrating these components as business models and information technology improve over time.

The strategic vision for interoperability described in this document applies throughout the electric energy generation, delivery, and end-use supply chain. Its scope includes interactive technologies and business processes from the bulk power transmission system level to the lower voltage distribution system level and to the millions of appliances that are becoming equipped with processing power and communication interfaces. A transformational aspect of a vision for interoperability in the future electric system is coordinated operation of intelligent devices and systems at the edges of the grid infrastructure.

INTEROPERABILITY

The ability of two or more systems or components to exchange information and to use the information that has been exchanged.[1]

VALUE OF INTEROPERABILITY

- Reduces the cost and effort for system integration
- Improves grid performance and efficiency
- Facilitates more comprehensive grid security and cybersecurity practices
- Increases customer choice and participation
- Establishes industry-wide best practices
- It is a catalyst of innovation

The growing penetration of distributed energy resources (DER)[2] presents new issues for integrating these devices and systems and coordinating their operation with the electric system. This challenge offers an example for addressing interoperability concerns throughout the electric system.

Integrating DER will be driven by information and communications technology standards that are DER technology agnostic. That is, different standards will not exist for photovoltaic (PV), electric vehicle (EV), various types of electric storage, or flexible demand-side resources. Instead, digital connection rules will be based on architectural principles that enable independent DER operators to offer the one or more types of DERs in a facility (e.g., a campus, building, EV parking lot, house, etc.) to safely and securely interact with a party responsible for proper operation with the electricity system. This will be

[1] This whitepaper is a distillation of the Grid Modernization Laboratory Consortium report. *Interoperability Strategic Vision: Enabling an Interactive Grid*. PNNL-26338, Draft, Pacific Northwest National Laboratory, Richland, Washington, April 2017. Accessed February 2018 at https://gridmod.labworks.org/sites/default/files/resources/InteropStrategicVision2017-04-11.pdf.

[2] Distributed energy resources include operationally responsive distributed generation, storage, and load.

done by evolving existing codes, standards, and guides in specific directions. These directions form the basis of a vision for the integrated operation of DERs with the electric power system.

This vision of integration will enhance interoperability through policies and standards-driven interface agreements such as those discussed below.

- The interface between DER facilities and the electricity delivery system as well as the responsibility of each interacting party will be clearly understood and guided by accepted grid architecture principles[3] to protect system safety and security.
- A common set of grid services (e.g., energy scheduling, energy reserves, frequency support, and voltage support) will evolve that will drive service-oriented agreements from electricity market providers.
- Operators responsible for safe and secure operation of the distribution system will have clearly understood roles to support "open access" by any qualifying DER facility.
- The operator of each DER facility will be responsible for direct operation of its DER equipment (not the distribution operator) to meet the comfort and productivity needs of the facility while participating in service-oriented agreements with electricity market providers and distribution operators.
- Different DER technologies will qualify for participation in a grid service agreement based on their ability to meet the services' performance requirements (e.g., amount of response, speed of response, and duration of response).
- For each grid service agreement, DER interface specifications will stipulate registration qualifications, the negotiation process, the operations process, measurement and verification, and settlement/reconciliation. These specifications will be subject to regulations and, therefore, will change from place to place. However, they will follow a common contract model to support machine-readable agreements.
- These DER integration and coordination interfaces will be supported by robust distributed information technology integration platforms used in many business domains and will not be restricted to the electric industry.

Interoperability has important economic consequences. Systems that integrate simply and predictably have lower equipment and transaction costs, higher productivity through automation, better conversion of data and information into insight, greater competition between technology suppliers, and more innovation of both technology and applications. Those systems propagate faster, use resources more efficiently, and create more value for their users. Such systems consistently prove that interoperability standards and supporting integration mechanisms enhance user choices, because they create a framework within which vendors and their competitors can innovate to provide new products that deliver new functions that previously were unattainable or even imaginable.

CONTENTS

[3] Taft JD and A Becker-Dippmann, *Grid Architecture*, U.S. Department of Energy. PNNL-24044, Pacific Northwest National Laboratory, Richland, Washington, January 2015. Accessed February 2018 at https://gridarchitecture.pnnl.gov/media/white-papers/Grid%20Architecture%20%20-%20DOE%20QER.pdf.

VISION OF A DESIRED FUTURE

Interoperability is a quality or characteristic related to the problem of integrating two or more devices or systems across an interface. The goal is for interoperability to be achieved with minimal expenditure of time and money. The desired characteristics of the integration experience with respect to meeting interoperability requirements are illustrated in Figure 1 through a simple "integration future scenario." The characteristics and challenges of realizing the desired future are then discussed, and a high-level strategy for the path forward is summarized.

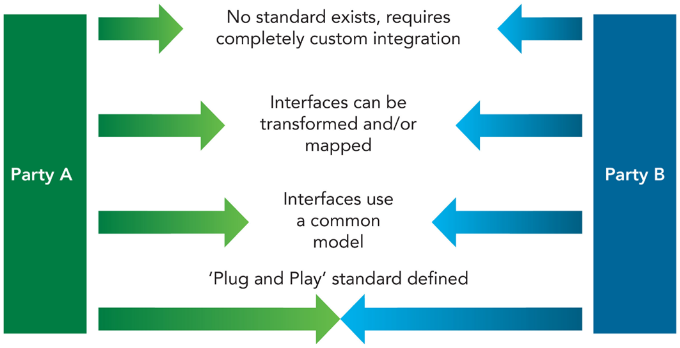

Figure 1. The Distance to Integrate[4]

Many people are familiar with the term "plug-and-play." In the simplest terms, it represents the desired integration experience we strive for to attain interoperability. We envision that DER, distribution automation equipment, and other software and hardware elements of a modernized electric power system could be easily, if not automatically, installed and integrated with minimal effort beyond the physical installation or interconnection process. When this result is achieved, we have fully "reduced the distance to integrate" as illustrated above.

The following scenario is an example of the desired integration experience. The scenario is built around a homeowner installing a smart charger for an EV. The elements of the scenario are:

- *Integrator* – The homeowner/EV owner
- *Others Supporting the Integrator* – An electrician
- *Point of Integration* – The homeowner's home
- *Components* – The EV charger
- *Interface to be Integrated* – The electrical connectivity of the EV charger and information connectivity of the EV charger to the energy service provider.

DESIRED INTEGRATION EXPERIENCE

Interoperability for electric grid integration involves a physical connection that enables the flow of electricity and information and some minimal action to allow the flow of information. Once the interface has been configured, as automatically as possible, the flow of electricity is managed based on the exchange of information.

The story

Imagine Mr. Green has purchased an EV and is installing a Level-2 EV charger in his garage. His "smart" EV charger can respond to signals from his energy service provider, thus giving him the opportunity to manage the cost of charging his vehicle. The charger requires a 30-amp, 250-volt, NEMA[5] 6-30R, 2P, 3W Receptacle for operation.

Mr. Green hires an electrician to install a wall receptacle that meets these requirements in his garage.

[4] Neumann, S, Position Paper for the GridWise Interoperability Workshop, April, 2007. Accessed February 2018 at http://www.gridwiseac.org/pdfs/interop_papers_0407/papers/neumann.pdf
[5] National Electrical Manufacturers Association

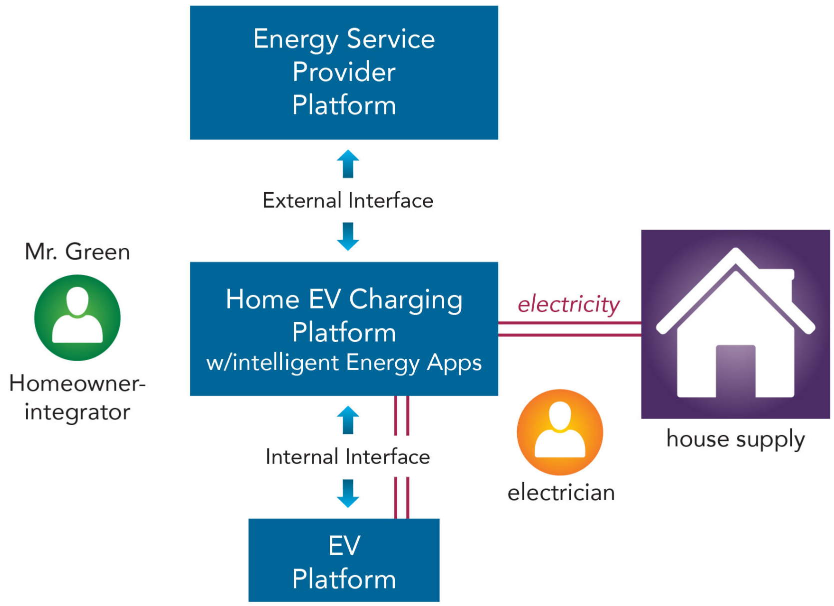

Figure 2. Integrating a Smart EV Charger

Mr. Green attaches his EV charger to the wall, plugs it into the receptacle, and powers it on. The EV charger searches for a wireless network, and the display prompts Mr. Green to select a wireless access point. Mr. Green selects his home network and enters the security passcode. The EV charger application then prompts Mr. Green to select his energy service provider from a list of energy service providers in his area. He selects his energy service provider, with whom he has already established an online account, and then is prompted to enter his account number. The EV charger then communicates with the energy service provider, identifies itself, and registers itself with them. Mr. Green is then prompted via an email message sent to him by his energy service provider to confirm the registration of his EV charger and to select his charging options and savings opportunities. In response to the email, Mr. Green confirms the registration, and selects an option for maximum savings with no financial penalty should he interrupt charging. The energy service provider and the EV charger exchange information enabling variable rate charging in the EV charger. At that point, Mr. Green can use the charger.

Note that Mr. Green only had to provide authentication information for the home network connection and the energy service provider account, and then select the options he wants. He did not have to provide details about the manufacturer of the charger or his vehicle. Figure 2 depicts the steps Mr. Green needed to achieve interoperability with his smart charging system.[6]

What has transpired behind the scene?

The EV charger and energy service provider have exchanged information that amounts to a handshake in which the EV charger identifies itself as an EV charger, and the energy service provider asks for identification by requesting the homeowner to enter his account number. Once the homeowner has confirmed the connection, the energy service provider queries the EV charger (possibly through preconfigured information exchanges that establish the way subsequent information exchanges will occur), configures the interface, and then determines the charger's capabilities. With this information, the energy service provider presents Mr. Green with the options available for the charger he has chosen. Mr. Green selects the desired options, and the energy service provider then provides any necessary configuration settings to the EV charger. Mr. Green or a professional installer did not have to engage in a complicated configuration process for the charging equipment. He only had to plug in the charger, establish a network connection, and select his options.

The desired characteristics of the integration experience resulting in interoperability can be more formally considered using the GridWise Architecture Council (GWAC) Stack framework as shown in Figure 3.

[6] The platforms and interface arrows in the figure refer to the information and communications technology components being integrated.

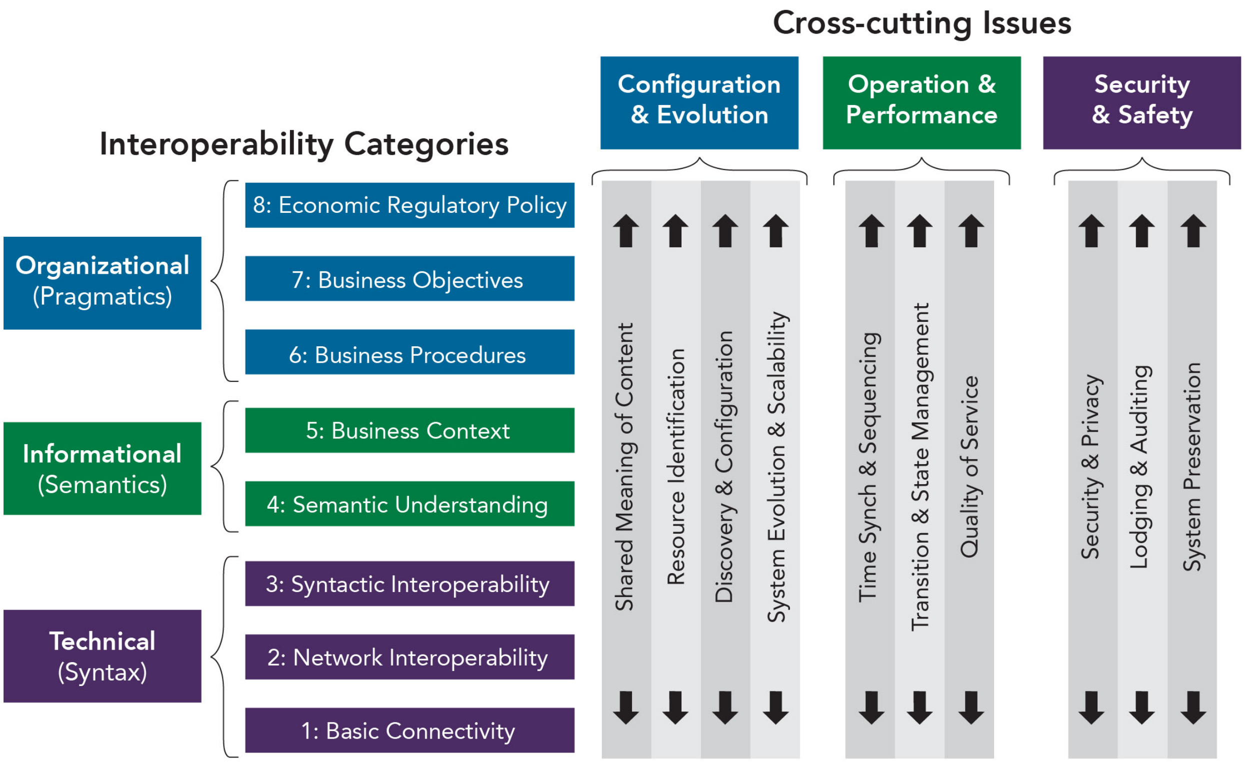

Figure 3. The Interoperability Context-Setting Framework[7]

This framework has eight layers grouped into three categories: 1) technical, 2) informational, and 3) organizational. Integrating at an interface requires the integrator to account for alignment in all eight layers. Achieving this requires shared understanding in the organizational and informational layers and a common approach to interconnection in the technical layers. The technical and informational layers require some degree of formal standardization. The organizational layers also require standardization, but as they involve business processes, rules, and policies, they require common understanding to be achieved through contracts or other forms of agreement on the role of the actors on either side of the interface. The Interoperability Context-Setting Framework helps focus discussion on categories of interoperability issues, such as the organizational (regulations, policies, contractual agreements and processes), informational (shared semantics, attributes, and relationships between types of information), or technical (communications networks and protocols) as well as cross-cutting issues such as security, privacy, and safety. All of these concerns must be addressed for interoperability to be promoted effectively.

A core architectural principle is to separate the technical (communications) layers from the informational and organizational (business) layer specifications. In many application domains (e.g., building automation systems or EV charging), some standards mix informational layer models with specific technical layer protocols. Such situations lack modularity in the distinct separation of layers through well-defined interfaces that would otherwise support the acceleration of innovation and adoption of standards by allowing each area to co-evolve on separate time lines.

[7] GWAC–GridWise® Architecture Council. 2008. *Interoperability Context-Setting Framework v1.1.* Accessed February 2018 at http://www.gridwiseac.org/pdfs/interopframework_v1_1.pdf.

ADVANCING INTEROPERABILITY

- *Vision* – Cultivate a shared understanding of the current reality and the desired future.
- *Methods* – Processes and tools to accomplish the shared goals: programs, regulations, incentives, education
- *Application* – Use of methods with engaged technology communities: their systems, solutions, and interactions.

To coordinate operation of a changing DER mix over time, integration of each resource must be simple and reliable. While each DER technology will have specific reasons for grid connectivity and may support different grid services, general integration mechanisms that span different technologies are needed to manage integration and operations costs. Because technology and business demands are continually changing, the path forward to advance interoperability requires continual improvement. This means developing alignment on a vision for the future, understanding the current state, identifying gaps, prioritizing needs, planning steps to meet the objectives of the vision, and repeating the process periodically to refresh future plans.

We propose a path forward with specific activities to effectively advance interoperability for grid modernization. The path draws on interoperability characteristics summarized later in this paper to explore a broad set of concerns. Stakeholder involvement is required for any plan to be adopted, and clear incentives must be understood by organizations to encourage their participation in the process. One way to encourage participation is to demonstrate advanced capabilities that hold promise to address today's interoperability shortcomings.

The vision for interoperability presented here is the starting point for establishing agreement with a community of stakeholders on a desired future. Sharing such a vision aligns the community directionally. The path forward for improving integration starts with establishing a vision of the concepts, structures, and characteristics that grid modernization participants accept as desirable.

With a shared vision, a community can assess where they are today, identify gaps between today's situation and the desired future, and develop plans to address those gaps in deliberate steps going forward.

APPLYING AN INTEROPERABILITY VISION TO DER INTEGRATION

The properties and concepts that surround interoperability apply to the integration of all smart, communicating devices and systems. The growing number of DER interactions with electric systems presents a timely integration challenge for applying these concepts and offers an example to help make these abstract concepts more tangible.

A framework for discussing DER interoperability

A discussion of the state of and future directions for advancing interoperability for DER integration with the electric distribution system can benefit from identifying the following types of concern:[8]

- The types of DER technologies being integrated
- The objectives or grid services that drive the reasons for coordinated interactions of DER with the grid
- The stakeholders and actors that influence these interactions.

[8] The types of concerns are adapted from Hardin DB, EG Stephan, W Wang, CD Corbin, and SE Widergren. 2015. *Buildings Interoperability Landscape.* PNNL-25124, Pacific Northwest National Laboratory, Richland, Washington. Accessed February 2018 at https://energy.gov/eere/buildings/downloads/buildings-interoperability-landscape.

We use the term DER facility to represent a grouping of assets related to the ownership and operation of one or more co-located DER devices and systems. Examples include a community PV system, an EV parking and charging center, a building with responsive load capabilities, or combinations of these things. Figure 4 shows representative types of technologies associated with DER facilities that are relevant for exploring integration.

DER integration ecosystems are created by organizational communities that share benefits in the advancement of efficient technology integration. Examples of emerging ecosystems in DER technology areas are identified in the above list of equipment types and decision systems. In particular, smart inverters (for batteries or PV systems) and automated buildings are technology types for which organizational ecosystems of companies are coalescing to advance market penetration. While these ecosystems are loosely confederated organizations that can adapt due to voluntary participation under changing market conditions, they represent industry alignment to develop and adopt standards and best practices.

INTEGRATION ECOSYSTEMS

A community of participating organizations collaborating to address one or more business or social objectives that concern interoperability and ease the deployment of specific technologies. The participants in such communities represent many types of organizations that are needed to support integration objectives. These include managers-owners-users, technology suppliers, service providers, distribution system operators, regulatory and government agencies, consortia/trade associations, and testing-certification bodies. They have an established convening body with champions who drive the group toward alignment in achieving their shared objectives.

The purpose of integrating DER flexible operation with the electric grid is to achieve one or more operational objectives, including efficiency, reliability, stability, and resilience to abnormal situations. To effectively integrate DER, these objectives become translated into a set of operational compacts or contracts associated with grid services. While each jurisdiction may have somewhat different definitions and contractual terms for grid services, the types of services fall into generally recognized categories by grid operations. A representative list[9] of these categories follows. While they may be mainly apparent to bulk power operations, their translation at the distribution level and DER facilities in particular is an open area. Today, few if any of these grid services are available for DER coordination.

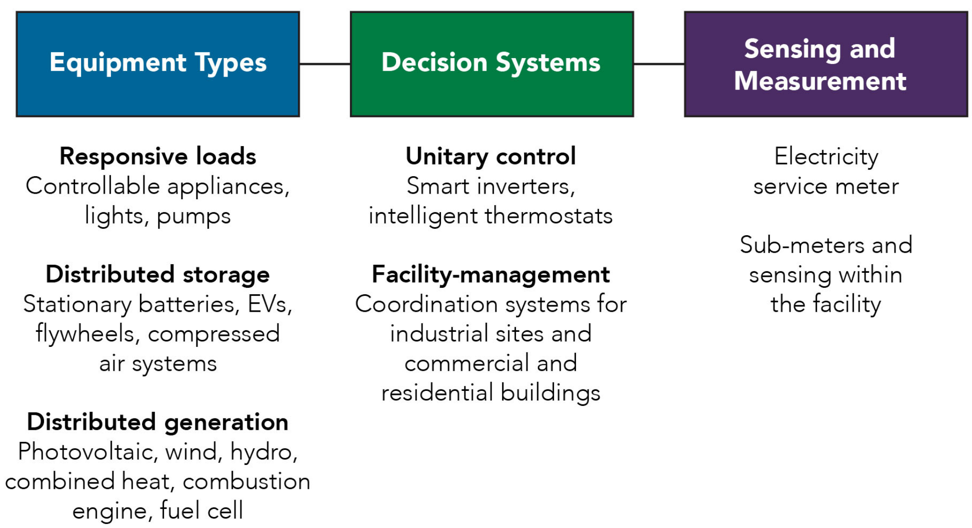

Figure 4. Representative Technologies Relevant for Exploring Integration a DER Facilities

[9] Proposed by Pratt, RG, ZT Taylor, *Recommended Practice for Characterizing Devices' Ability to Provide Grid Services*, PNNL-26252, a US Department of Energy Grid Modernization Laboratory Consortium 1.4.2 project report, March 2017.

- *Energy Market Price Response* –Reduce net load when prices are high or increase net load when prices are low. The objective is to reduce wholesale energy production or purchase costs and ensure that non-dispatchable generation is not wasted.
- *Peak Capacity Management* –Reduce net load as needed so it never exceeds the capacity of the grid infrastructure to deliver power to a region. The objective is to reduce the need for capital expenditures for generation, transmission, and distribution capacity expansion or upgrades.
- *Spinning Reserve* –Remain on standby, ready and able to rapidly reduce net load and sustain the reduction until replaced by non-spinning generators that are available. The objective is to rapidly restore balance between supply and demand when an unexpected event occurs.
- *Meet Obligation to Supply Capacity in a Wholesale Energy Market* – Reduce net load when called upon to meet a contractual obligation to do so by receiving a capacity payment. The objective is to ensure the existence of sufficient regional generation capacity and obtain it from the lowest cost resources using a wholesale capacity market.
- *Frequency Regulation* –Increase or decrease net load to restore balance between supply and demand in response to a ~4-second interval signal from a system balancing authority. The objective is to maintain grid frequency by adjusting to errors in scheduled imports and exports for a regional balancing authority's area.
- *Ramping* –Be on standby ready to increase or decrease net load when the available generation cannot change its output rapidly enough to follow changes in total net demand. The objective is to help meet the sustained rapid change in total generation caused by renewable production.
- *Artificial Inertia* –Self-sense when grid frequency drops rapidly and act to complement the grid's angular momentum and generator governor controls by immediately increasing or decreasing net load. The objective is to arrest a precipitous change in frequency that begins instantly when an unexpected event occurs.
- *Distribution Voltage Management* –Self-sense when the distribution voltage goes outside its operating limits, and act by adjusting local load in the form of its reactive and/or real power components. The objective is to maintain distribution system voltage within its normal range in response to changing operating conditions.

A set of partners interact with the DER facility to conduct various grid services. These parties are the actors in interaction use cases with the DER facility. They are important participants in integration ecosystems.

- *DER Operations* – The party responsible for operating a DER facility (e.g., building, EV charging lot).
- *DER Community* – A collection of DER facilities that do not share owners or operators but have characteristics that enable them to work together to coordinate and optimize energy use under a variety of conditions.
- *DER Service Provider* – A supplier of a range of services to DER facility owners and operators. These providers could manage DER operation for financial benefit of the DER owner in reducing utility bills. They also could perform monitoring, diagnostics, and troubleshooting and support.
- *Market Service Provider* – This party provides retail market operations under electricity service agreements to DER facilities. Market service providers also interact with other electric power grid service actors at the bulk system level and with distribution system operations actors. In this role, they act as a middle man so DER facilities do not need to interact directly with bulk-system-level actors. An example of a market service provider is a DER aggregator.
- *Distribution System Operations* – This party is responsible for reliable operation of the distribution system. Market service providers interact with distribution system operators to ensure that their service to DER facilities addresses requirements for reliable delivery of electricity.

Additional categories of stakeholders involved in DER grid-integration ecosystems and not necessarily the coordinated operation of DER for grid services include the following:

- DER owners and users
- DER equipment suppliers (hardware manufacturers)
- DER energy-management system suppliers (generally automation software suppliers)
- Communications infrastructure and service providers
- Regulators and government agencies
- Trade associations, industry consortia, and standards development organizations
- Testing and certification organizations.

The Energy Services Interface (ESI)

Grid architecture provides concepts, principles, and structure that help identify the location and define the form of interfaces between connected devices and systems, such as the grid and DER. This directly affects the effort of achieving interoperability. Grid architecture also helps inform the extent of system vulnerabilities to safety concerns and cybersecurity risks.

An important architectural principle applied to electric power system control/coordination frameworks is layered decomposition.[10] This principle has been used to show commonality across a range of existing and proposed control/coordination architectures. The basic approach of layered decomposition is to decompose the system coordination objectives into a master problem and several sub-problems, which are solved iteratively until they collectively converge. Each sub-problem also may be decomposed recursively into set of additional sub-problems. Each level of these nested sub-problems can be considered a coordination domain. Figure 5 depicts a layered decomposition view of power system coordination. At the top is the regional, transmission coordination domain, which interacts with the distribution systems operations coordination domain. In turn, the distribution systems operations coordination domain interacts with the primary distribution substation domain, which can interact with further decomposed domains until eventually the DER coordination domain is reached.

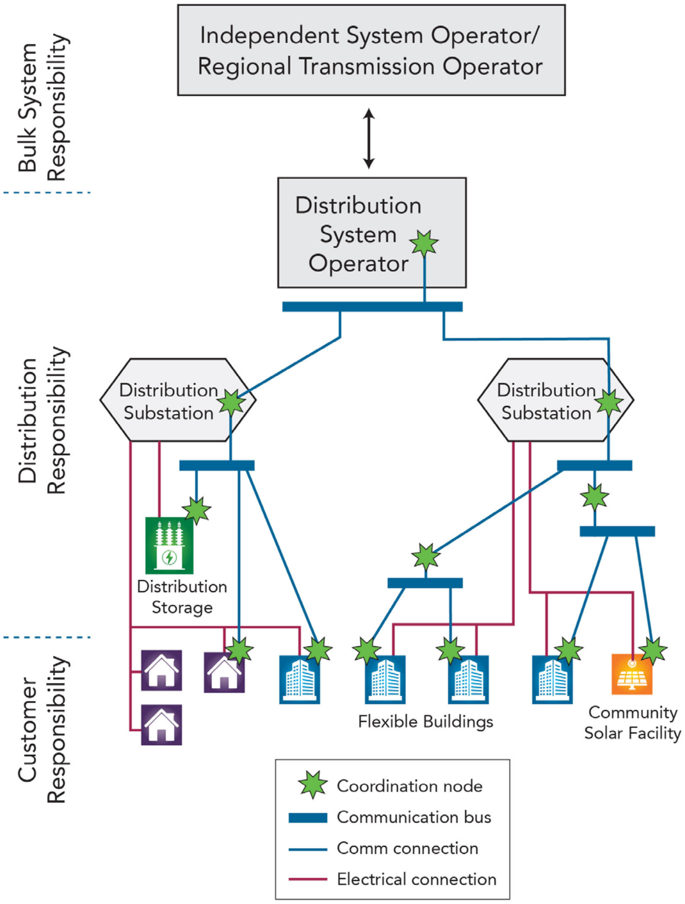

Figure 5. Utility Architecture View with Layered Decomposition Coordination

Coordination interactions that skip layers of the coordination framework structure can lead to less optimal or unstable behavior. For example, a DER market provider that aggregates responsive equipment for interactions with independent system operator (ISO) energy markets cannot reliably coordinate with sub-problems at the DER

[10] Taft, JD. 2016. *Architectural Basis for Highly Distributed Transactive Power Grids: Frameworks, Networks, and Grid Codes.* PNNL-25480, Pacific Northwest National Laboratory, Richland, Washington. Figure 5 is an abridged adaptation of a drawing in this report.

facilities level if the coordination frameworks of the affected distribution system operators are not also part of the coordination. How else would such a solution process know if a distribution system delivery constraint was violated?

The concept of an ESI enforces the layered decomposition principle for integrating DER facilities with the grid.

> "An ESI is a bi-directional, [*service-oriented*], logical interface that supports the secure communication of information between entities inside and entities outside of a customer boundary to facilitate various energy interactions between electrical loads, storage, and generation within customer facilities and external entities." [11]

A DER facility defines the boundary of the customer's devices and systems that, to be grid responsive, use automation to manage their operation. They interact by supporting an ESI to external interacting parties in the electric system (see Figure 6). We introduce the concept of a facility-management function to generalize the idea that DER equipment has some intelligent coordination aspect. This allows decoupling of integration (and interoperability) concerns between stakeholders involved in internal interactions (e.g., equipment and facility controls suppliers) and those involved with external interactions (e.g., facility controls suppliers, distribution system operators, and market service aggregators).

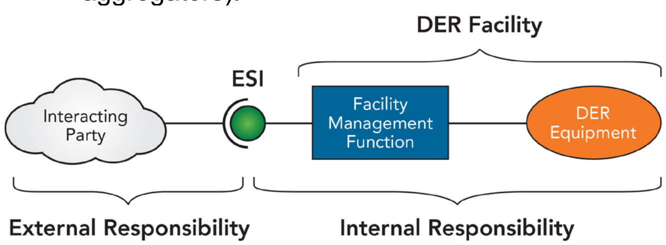

Figure 6. Components of DER and Grid Integration

The facility-management function could be as simple as a communicating controller embedded in the smart inverter of a battery storage device or as complex as a management system for a large commercial building, manufacturing facility, campus, or EV charging parking lot with PV arrays. To interact with DER equipment, the facilities management function coordinates using internal interfaces with the DER equipment. To coordinate with external parties, it supports the ESI.

The ESI definition stated above includes the notion of being service oriented. This is a software interface approach that emphasizes what is expected (a service) and separates or hides how that service is performed. In the case of DER integration, it means that external parties do not need to know how the DER facility manages its DER equipment as long as the requested service satisfies the terms of the agreement (e.g., performance measures). Much of today's computer software uses the service-oriented design paradigm to emphasize separation of responsibilities between interacting software components. By defining and providing access to a service (or method in an application programming interface in information technology terms), a program offers a way for a "user" to accomplish a specific task. A service provider stipulates the nature of the service in a description of its function, its inputs and outputs, its performance guarantees, and important operational details such as what happens if it cannot complete the task (e.g., an error is encountered). The user or "caller" of the service provides the required input parameters and receives the outputs, including the anticipated work to be accomplished. Importantly, the user does not know "how" the service was supported. That is the responsibility of the service provider. In this way, the service provider may change and improve the way the work is accomplished without any change to the service interface. That decoupling of concerns improves interoperability because the user of the service does not even need to know that a change has occurred, as its side of the connection is unaffected. We use a Unified Modeling Language ball and socket connector symbol to indicate an ESI as a simple "port." In practice, an ESI may be defined with a set of ports arranged in both internal and external directions.

[11] Hardin D. *Customer Energy Services Interface White Paper.* Grid-Interop Forum 2011. Accessed February 2018 at http://www.gridwiseac.org/pdfs/forum_papers11/hardin_paper_gi11.pdf. Note, the words "service-oriented" are added to the definition here.

By expressing grid services using a service-oriented paradigm in an ESI specification, a DER facility has the opportunity to provide the same service for any DER equipment at its disposal as long as it satisfies the inputs and outputs and the performance guarantees. This approach provides focus for conventions, guides, and standards that simplify integration of DER facilities with the grid so that their interactions with external parties are similar regardless of the type of DER facility being integrated. It also provides a buffer to separate integration issues associated with communicating with devices internally to the DER facility. That separation is important because internal DER facility integration issues usually have different requirements and involve a different community of people than the integration issues with external parties.

Figure 7 expands the basic concept of a DER facility to indicate that it may encompass one or more types of DER with some sort of facilities management function. This system is able to interact with external parties using an ESI. The classes of interacting parties are indicated by the clouds connected by communication paths on the left to the ESI and the types of DER equipment are indicated by the ovals connected by different communication paths on the right. Another important concept included in Figure 7 is the meter. To reconcile the resulting actions of a DER facility with the coordinating agreements, sensing and measurement systems need to be in place. The electric meter monitors the flow of energy between the DER facility and the electric system. A dotted line indicates the communication path that connects it to distribution system operations, which is the authority responsible for reliable operation of the distribution system. The sets of solid and dotted lines of communication represent integration interfaces for discussing interoperability issues.

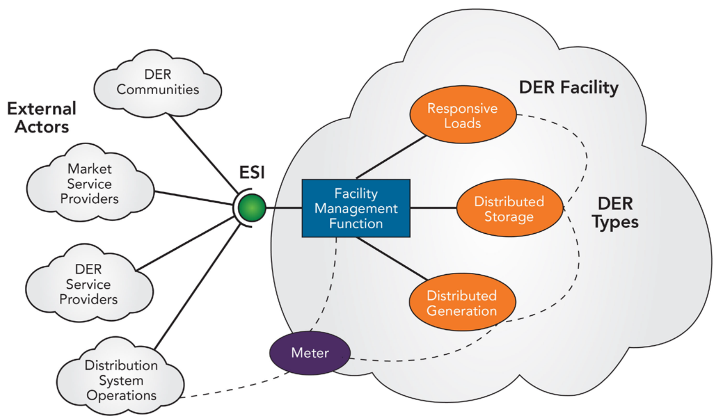

Figure 7. Visualization of a DER Facility Conceptual Model[12]

The State of DER Interoperability

At the interoperability organizational level, today, there are few grid services available for DER coordination. Most DER facility interactions are directly controlled by utilities or third-party aggregators. Service contracts may or may not stipulate the purpose for control so the grid service or system objective is not always apparent to the DER facility. Some programs are designed to encourage consumer behavior changes in ways that help system operations without using direct-control methods. Examples of these programs include tariff schemes, such as demand capacity charges that provide an incentive to stay below a power or energy limit, or time-of-use programs that change the price of energy depending on when it is consumed. Systems in which prices are dynamic beyond fixed schedules currently are rare, but interest in variable rate scheduling is growing.

In most regions, system operators offer demand response (DR) programs. These programs are used primarily for peak capacity management and

The ESI concept benefits distribution system operators and DER aggregators by greatly simplifying their interaction with a large and diverse set of DER. It benefits DER owners and operators by simplifying their interactions with a potentially large and diverse set of external parties while allowing their internal systems to be maintained and evolve separately across a range of DER technologies, thus enforcing a respectful level of privacy.

[12] Hardin DB, EG Stephan, W Wang, CD Corbin, and SE Widergren. 2015. *Buildings Interoperability Landscape.* PNNL-25124, Pacific Northwest National Laboratory, Richland, Washington. Accessed February 2018 at https://energy.gov/eere/buildings/downloads/buildings-interoperability-landscape.

spinning reserve grid services. Market service providers (i.e., aggregators) of DER qualify to participate in these markets by coordinating the operation of many DER facilities to reach the minimum size needed. Observations about the interoperability organizational characteristics for these aggregators of DER include the following:

- They tend to use proprietary communications and control systems to directly control DER and either work with a customer's facility-management system to control the local equipment or control the DER equipment directly with the aggregator's own control technology.
- DR market interfaces are market-provider-dependent and not standardized across ISO market systems, making it necessary for DER aggregators to customize their technology to support different DR power markets.
- The interfaces between aggregators and the DER facilities are usually aggregator-dependent and also are not standardized. This hinders the ability of DER facility managers to easily change aggregators, although in some jurisdictions, standards such as OpenADR and IEEE 2030.5 are being used to attain greater interoperability.
- From an architectural coordination framework perspective, there is little recognition of a layered decomposition requirement to include coordination between aggregators working with the DR markets from those responsible for the reliable operations of the distribution system. This could lead to potential operations problems when DR programs scale to high penetration levels within a distribution feeder.
- There is a deficit of quantitative analyses on the costs and benefits of promoting interoperability, or adopting associated open interoperable standards at the distribution system level.[13] While benefits are recognized in general statements, the lack of substantive approaches for estimating the financial benefits of interoperability make policy decisions directed at systematically encouraging processes or investments that promote interoperability difficult to institute.

At the interoperability informational level, given that there is no general agreement on the concept of an ESI for a DER facility or the definition of grid services, the emerging information modeling standards are specific to each DER technology ecosystem (e.g., EVs, PV systems, and automated buildings). The format and information science-based methods and tools, such as the Unified Modeling Language, and the knowledge representation for defining information models is not consistent among ecosystems. Some information models are extensions of existing standards that use specialized modeling language formats, making harmonization of standards across different ecosystems difficult. Existing information models also tend to support direct-control types of interactions with DER equipment for reading and writing information rather than service-oriented message exchanges; however, information models in standards that could support service-oriented message definitions with the ESI of a DER facility are starting to be adopted for specific ecosystems.

At the interoperability technical level, aspects for integrating DER are addressed by a wide variety of standards. These are mature standards that support all forms of wired and wireless communications. At the communication protocol level, everything from DER equipment to DER facility-management integration is using a wide variety of standards, some open and some proprietary. Each DER technology ecosystem has its own, often competing, set of protocols for communicating with DER equipment. Electric utility-oriented projects tend to use technical-level standards derived from electric power field equipment automation standards, while DER equipment suppliers tend to use standards developed in their professional areas.

Cybersecurity issues exist across the organizational, informational and technical level. Most DERs operate without any cybersecurity requirements, though standards specifying cybersecurity aspects are improving. Even in

[13] ICF. 2016. *Standards and Interoperability in Electric Distribution Systems*. Accessed February 2018 at https://www.energy.gov/sites/prod/files/2017/01/f34/Standards%20and%20Interoperability%20in%20Electric%20Distribution%20Systems.pdf.

California, where the California Independent System Operator has set cybersecurity requirements for DER providers, these requirements stop at the DER aggregator level—DER facilities internally operate without cybersecurity requirements. Standards that could be useful in cybersecuring DERs do exist. For example, IEC 62351 is a standard designed to address cybersecurity in the electric utility infrastructure field and is applicable for a number of other power systems field communication standards. In addition, more generally applied, non-utility cybersecurity standards such as IEEE P1363 (public-key cryptography), IEEE P1619 (encryption of stored data), and IEEE 802.1AE (connectionless data security for media access) may be helpful. However, the application of these standards remains project specific. New versions of standards, such as IEEE 2030.5, are addressing some cybersecurity aspects, such as encryption.

A Strategy for DER Interoperability

To coordinate operation of a changing mix of DER over time, integration of each resource must be simple and reliable. While each DER technology will have specific reasons for grid connectivity and may support different grid services, general integration mechanisms and concepts, such as the ESI, that span DER technologies are needed to control costs. Because technology and business demands are continually changing, the path forward to advance interoperability requires continual improvement. This means achieving alignment on a vision for the future, understanding the current state, identifying gaps, prioritizing needs, planning the steps to meet the objectives of the vision, and periodically repeating the process to refresh plans. Stakeholder involvement is required for any plan to be adopted, and clear incentives must be understood by organizations to encourage their participation in the process.

To advance integration of all types of DER technology, a cross-technology coordination strategy on a vision for integration with the grid can emphasize aspects of interoperability that can become common to across technology deployments. Such a strategy encourages consistency of concepts and a convergence of approaches that can lead to consolidation of standards and conventions for integration with electric system operators and DER aggregators (Figure 8).

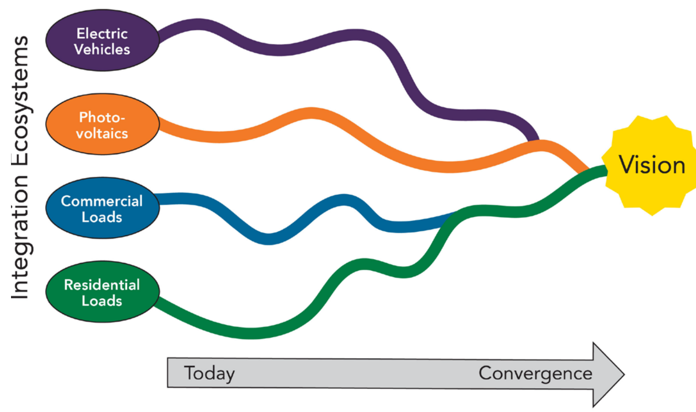

Figure 8. Convergence of Roadmaps for DER Interoperability

The strategy must acknowledge that real progress for adoption requires action in integration ecosystems where value propositions are tied directly to the process of aligning stakeholders. This begins by establishing guidelines and technical standards for the interface points of integration. To ensure that different implementations of standards-based interfaces can work together and achieve reliable integration experiences, testing and certification programs need to be set up and supported by the ecosystem. In addition, interoperability agreements need to be promoted to the marketplace that is supporting the business propositions of ecosystem members. Techniques such as branding and education programs can be used to facilitate adoption of such agreements. Each of these items are non-trivial and require years to implement and maintain. Efforts to move different ecosystems toward a common interoperability vision involves careful planning that considers all of these aspects.

To execute this strategy requires a methodical approach. Outreach is needed to involve the relevant integration ecosystem parties in roadmap planning and decision-making activities where they retain ownership and commitment. Methods and tools for measuring the state of interoperability and developing roadmaps that incorporate the integration vision can facilitate participant actions within these integration ecosystems. To ensure participation in interoperability assessment and roadmap development, incentives such as the technology procurement language or interoperability incentives from policymakers would be helpful.

Table 1 lists strategic activities to advance interoperability for grid modernization and DER integration. The statements start with a set of general actions for the grid modernization community followed by activities organized using the interoperability categories and cross-cutting issues described by the Interoperability Context-Setting Framework.

In addition, government an play an important role in an interoperability strategy by driving initiatives with the following goals:

- *Interoperability Path Forward* – Bring stakeholders together to achieve alignment on the vision, the state of interoperability in general, and a general path forward with industry and government roles identified.
- *Ecosystem Roadmaps* – Identify and engage early adopter DER technology integration ecosystems to apply a roadmap development methodology with tools to measure the state of interoperability in each specific ecosystem and identify challenges and opportunities. Encourage convergence on standards and practices where rational.
- *Advance Interoperability Capabilities* – Support (with industry involvement) the demonstration of advanced interoperability capabilities (e.g., challenge/prize event to solicit proposals leading to projects that demonstrate advanced integration capabilities).
- *Lead by Example* – Work with one or more government agencies to adopt interoperability performance criteria in procurement specifications where DER facilities are being integrated with the grid.
- *National Registries* – Work with industry to establish and support a global DER facility unique identification approach to support registration and authentication capabilities.

TOOLS AND TECHNIQUES TO ADVANCE INTEROPERABILITY

The strategic vision for interoperability proposed in this document focuses on a process for aligning those people and organizations working in specific grid-integration domains (e.g., EVs, PV systems, responsive buildings, etc.) toward a shared goal so each stakeholder sees its relevance to their cause. It should elevate notions of simplicity and harmony that can be difficult to imagine under existing regulatory policy, business objectives, legacy technology investments, current agreements, and other immediate constraints.

Once a shared vision is established, the steps required to achieve that vision (i.e., a roadmap) can be considered. A stakeholder roadmap development process is used to improve the integration of intelligent electric equipment and systems. Besides providing an organizational structure for stakeholder engagement, the roadmap process also applies a set of tools for specifying interoperability characteristics that support the measurement and assessment of maturity levels of interoperability. This includes everything from business and regulatory issues to network protocols that carry the messages and support business processes. Such an assessment is built upon a clear map of interoperability characteristics that support simplification of the integration experience. The methodology and tools can be applied to many types of device or system interfaces. We focus here on the timely topic of DER integration to propose a set of activities to bring commonality of approach and encourage convergence on agreements that can apply to all the diverse DER types.

This involves facilitating creation of a set of generalized grid services and identification of performance characteristics required to provide each grid service regardless of the type DER. By focusing on the qualifications for providing a service, the integration agreements needed should be simplified. In addition, commonality of approach to addressing interoperability gaps can lead to tools, techniques, best practices, and capabilities that can be leveraged across all types of grid-integration scenarios. Working both within

Table 1. Strategic Activities

Area	Activity
Community	*Interoperability Vision* – Socialize the definitions, concepts, and architectural structures to support the integration vision (e.g., layered decomposition coordination framework and ESI concepts for DER facility external interface interactions).
	Communities & Ecosystems – Identify the communities or ecosystems, and plan to engage these communities using the roadmap methodology and tools to define state, identify gaps, and prioritize steps forward.
	Encourage Interoperability Culture – Develop initial pro-forma procurement language to encourage interoperable investments with those who make technology investments. Make this readily available to the greater DER community. Sponsor reference implementations in challenges, prizes, or projects that advance the state of the art for interoperability. Recognize champions for interoperability in professional societies and trade groups.
	Marketing, Communications, and Education – Develop introductory material for tutorial material on interoperability, its benefits, and how to measure its qualities. Plan and support public presentations at conferences, webinars, and in publications (e.g., technical journals and industry trade magazines).
Configuration and Evolution	*Resource Identification* – Support unique identification management for all DER facilities to external parties and all DER equipment within DER facilities. The support should include a path for legacy devices and systems to be supported.
	Registration and Discovery – Support registration and discovery mechanisms for all DER facilities to external parties and all DER equipment within DER facilities. The support should include a path for legacy devices and systems to be supported. The mechanisms may initially be ecosystem dependent, with steps to encourage a consolidation of approaches.
	Scalability – Document requirements and demonstrate scalable approaches for DER integration and coordinated operation.
Security and Safety	*Security Policies* – Work across ecosystems to develop best practices for security policies in interface specifications for both external and internal interactions associated with DER facilities. This includes methods to quantify risk associated with the compromise of individual DER and the aggregate risk arising from the compromise of large numbers of DER.
	Privacy Policies – Work across ecosystems to develop best practices for privacy policies in interface specifications external and internal to DER facilities.
	Failure Mode Policies – Support electric system industry initiatives for high penetration of DER on grid codes or best practices for safe-mode operation during failures in communications or the DER facility and DER equipment to honor grid service agreement. Move from DER-type dependencies to generalized DER performance dependencies.
Operation and Performance	*Operations and Performance Characteristics* – Document the performance and reliability, error handling, time-ordered dependency, time synchronization, and transaction and state management requirements. These are important for DER facilities to qualify for specific grid services, in defining expectations, and establishing ratings and certifications for DER equipment.
	Ratings and Certification – Establish programs to rate and certify products to common operation and performance specifications for supported grid services requirements across all DER integration ecosystems.
Organizational	*Model Interface Specification Framework* – Define a template for interface specifications. The model should cover the specification of how interoperability characteristics are addressed for each DER facility interaction with external parties and with internal DER equipment. This includes the following: discovery/registration/qualification process, negotiation process for a grid service, operations process, measurement & verification, settlement and reconciliation
	Grid Services for Interoperability – Establish or adopt a grid services reference model for DER participation with electric system parties.
Informational Activities	*DER Performance Characteristics* – Define an information model of the performance characteristics required to qualify for specific grid services. (GMLC 1.4.2 Grid Services Equipment Characteristics is specifying the general characteristics independent of the type of technology.)
	Information Modeling – Define information models used in the external and internal DER facility interactions using well-recognized modeling language. The information models used for different energy technologies should converge to a model common for all types of technology to support the ESI concept.
Technical	*Consolidate Protocols* – For each ecosystem, develop plans to consolidate (deprecate/reduce) the number of protocols used in new deployments. Ensure technical communication network layers are defined independent from informational and organizational characteristics.
	Transition Path – Develop transition paths for legacy protocol deployments within ecosystems.

and across technology communities (i.e., ecosystems) will be required to achieve the level of alignment made apparent by the vision of a modern highly interoperable energy grid.

Given a way to measure and assess the state of interoperability and a vision for the desired state of interoperability, a set of gaps and challenges can be identified. These gaps and challenges then can be translated into a roadmap for how to improve interoperability using a process of prioritization and consensus building.

You can't manage what you can't measure.

Maturity model

Although the benefits of interoperability are widely acknowledged, their values are difficult to quantify.[14] Finding ways to measure the state of the complex dimensions of interoperability can help organizations and communities clarify gaps and challenges.

An element of this project is to articulate important characteristics of interoperability as a way to measure the state of interoperability in specific technology deployment domains, such as substation automation, or the integration of DER technologies. Using maturity models is a way that provides a measurement structure for assessing how a set of characteristics has evolved. Most maturity models conform to some common structural foundations. This structure is important because it helps provide clarity to a complex set of concerns that contribute to interoperability and their value propositions. The basic elements of a maturity model include the following:

- *Levels* – Levels represent explicit states in a maturity model. Each level may be a progressive step or plateau, or may represent an expression of a capability or other attribute that can be measured by the model.
- *Categories* – Categories are a means for grouping like attributes into an area of importance for the subject matter and intent of the model. Depending on the model, users may be able to focus on improving a single category or a group of categories.
- *Criteria* – Criteria are the core content of the model and are grouped by category and level. They are typically based on observed practice, standards, or other expert knowledge, and can be expressed as characteristics, indicators, practices, or processes.
- *Appraisal and Scoring Methods* – Appraisal and scoring methods are developed to facilitate assessment using the model as the basis. They can be formal or informal, expert-led, or self-applied. Scoring methods ensure consistency of appraisals and a common standard for measurement.

An interoperability maturity model (IMM)[15] is a tool used to measure the state of integrating the information and communications technology aspects of intelligent devices and systems to coordinate their operation with other devices and systems in the electric power system. Using such a tool can point out challenges and areas for maturity improvement to more easily and reliably achieve interoperability.

The IMM tool helps users identify gaps between current and desired maturity levels of interoperability and, in so doing, can lead to actions that make integration easier, less expensive, and more cost effective. When such a tool is applied within a roadmap development process, the resulting roadmaps can guide interoperability improvement efforts.

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[14] ICF. 2016. *Standards and Interoperability in Electric Distribution Systems*. Accessed February 2018 at https://www.energy.gov/sites/prod/files/2017/01/f34/Standards%20and%20Interoperability%20in%20Electric%20Distribution%20Systems.pdf.

[15] *A Qualitative and Quantitative Approach for Measuring Interoperability*. PNNL-26412, Draft, Grid Modernization Lab Consortium published by Pacific Northwest National Laboratory, Richland, Washington, April 2017. Accessed February 2018 at https://gridmod.labworks.org/sites/default/files/resources/InteropIMMTool2017-04-22.pdf.

Measurement criteria

The state of interoperability maturity can be measured by evaluating the various interoperability categories in the IMM. It is important to ensure model criteria are measurable to determine the state and any change in the condition of that state over time. Well-articulated interoperability criteria also can inspire the creation of performance requirement statements in procurements and also can be used to explore the maturity of the processes in place to improve the qualities of interoperability that simplify integration.

To measure interoperability, a set of criteria needs to exhibit several specific characteristics. These include being traceable, unambiguous, measurable, testable, consistent, uniquely identified, non-prescriptive, independent of each other, and negotiable. A set of categories are discussed below. The categories are used to organize interoperability criteria statements.

- *Configuration and Evolution* – Addresses topics relating to vocabularies, concepts, and definitions across multiple communities and companies. They include the ability to upgrade (evolve) over time and to scale without impacting interoperability. This is important as new automation components enter and leave the system.
- *Security, Safety, and Privacy* – Concerns aligning security and safety policies, and maintaining a balance of the tension between minimizing exposure to threats while supporting performance and usability.
- *Operation and Performance* – Focuses on timing requirements, quality of service, and synchronization as well as operational concerns (e.g., maintaining integrity and consistency during fault conditions that disrupt normal operations).
- *Organizational* – Covers the pragmatic aspects of interoperability. They represent the policy, business drivers, and business processes for interactions.
- *Informational* – Emphasizes the semantic aspects of interoperability. They focus on what information is being exchanged and its meaning, and focus on human recognizable information.
- *Technical* – Addresses the syntax or format of the information. They focus on the format information is represented within a message exchange and on the communications medium. They focus on the digital exchange of data between systems, encoding, and protocols.
- *Community* – The Community category crosscuts the other six categories. Its criteria focus less on the interoperability of systems and devices but more on the culture changes and collaboration activities required to help drive interoperability improvements that reflect the ecosystem's maturity with respect to interoperability. The criteria reflect the participation of organizations in efforts to improve interoperability in general, not just specific interfaces or processes.

Although the interoperability criteria have been organized into categories to facilitate participant focus on specific, related criteria for measurement, the category dedicated to safety, security, and privacy issues also has been the focus of its own maturity model[16] and is an area of increasing interest for the industry, not just from an interoperability perspective.

With good measures for interoperability characteristics, communities can better articulate the state of interoperability, organizations can better stipulate the desired level of interoperability performance from technology suppliers, and roadmaps can be developed to help ecosystems prioritize and focus their efforts to improve technology integration.

A facilitated process for group planning

Real progress to address interoperability is done by those working to achieve business and policy

[16] U.S. Department of Energy and U.S. Department of Homeland Security. 2014. *Electricity Subsector Cybersecurity Capability Maturity Model (ES-C2M2), Version 1.1*. Accessed February 2017 at https://energy.gov/sites/prod/files/2014/02/f7/ES-C2M2-v1-1-Feb2014.pdf.

objectives within ecosystems generally formed around promoting technology deployments. Development of standards and related testing material often is done with a requirements analysis based on present market needs for technology deployment. The process can be opportunistic, relatively narrow, and somewhat ad hoc. A roadmap methodology (i.e., the process of developing a high-level plan forward) geared to stakeholder engagement can provide perspective and direction to improve interoperability. A roadmap process involves understanding the state of interoperability and identifying gaps (both capability and implementation related) that can improve the situation. The process is supported by applying the IMM tool to measure the state of interoperability in specific integration ecosystems. Once these gaps have been identified, strategic plans can be developed to address the gaps.

The IMM consists of a set of broad questions plus descriptions to identify the level of maturity for each criterion. The results of going through the IMM questions with important representatives of an integration ecosystem can establish a baseline interoperability maturity level. This baseline can be used to compare against the target maturity levels for each criterion. The insights from this exercise can then be used to develop a set of prioritized actions to meet the desired target levels. The process of applying the IMM and then developing prioritized actions for improving interoperability capability fits into a roadmap development strategy.[17] Figure 9 shows the phases of the interoperability roadmap development process.

This process has been designed to emphasize stakeholder engagement in creating a roadmap with a guiding principle that once consensus is built among the participants toward shared goals and results, these relationships can help support roadmap implementation and also will increase the likelihood that the participants will join to implement the roadmap successfully.

The roadmap process helps the team to develop a clear vision of the target interoperability maturity as well as the specific steps for reaching it. Key elements of the process include the following:

- *Interoperability Maturity Goals* – These targets should be clear and concise. They should be designed such that, if achieved, the result will be the desired maturity level. IMM criteria are inherently designed to be quantifiable, which enables progress to be measured and provides clear, specific guidance.
- *Milestones* – These are interim targets for achieving the goals and should be keyed to specific dates.
- *Gaps and Barriers* – As identified above, one step in the analysis of IMM baseline results is a comparison against target maturity. This step builds on that step to create an understanding of gaps between current interoperability and barriers or obstacles to achieving the milestones and target maturity.
- *Priorities and Timelines* – Priorities and timelines identify priority actions required to achieve target interoperability maturity within the project timeframes and account for any dependencies between actions.
- *Roadmap* – The roadmap is the high-level plan for executing the prioritized actions that will be taken to achieve target maturity.

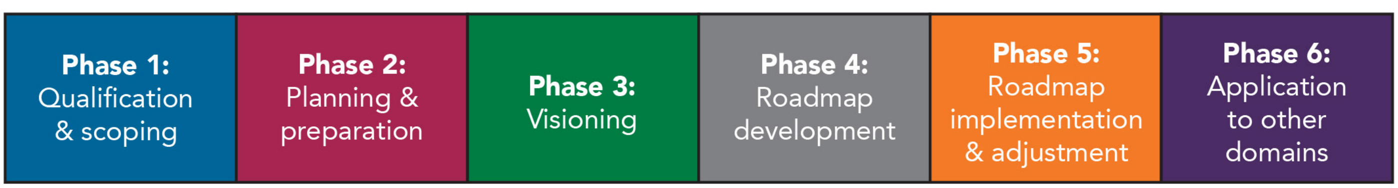

Figure 9. Roadmap Development Process

[17] *Interoperability Roadmap Methodology, V1.1,* PNNL-27149 1, Grid Modernization Lab Consortium published by Pacific Northwest National Laboratory, Richland, Washington, December 2017. Accessed February 2018 at https://gridmod.labworks.org/sites/default/files/resources/InteropRoadmapMethodologyV1-1.pdf.

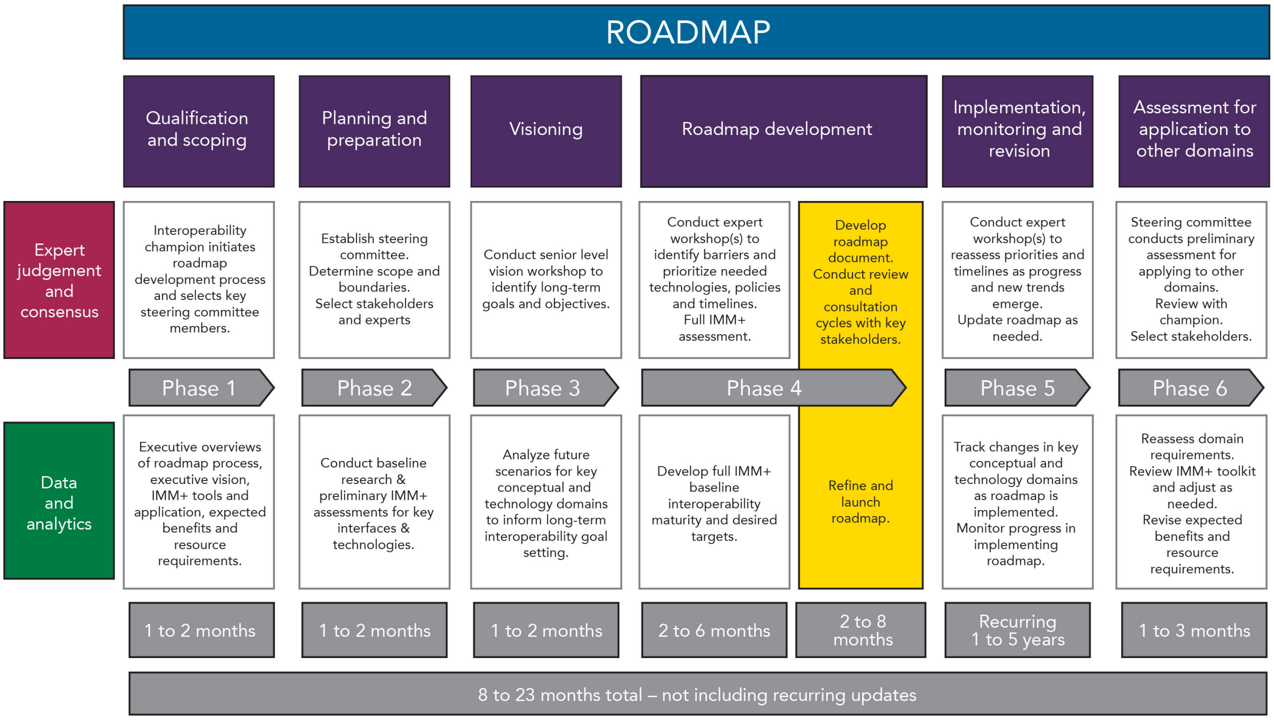

Figure 10. Roadmap Methodology

The overall roadmap process is presented in Figure 10. The IMM tool is required throughout the development process to inform the roadmap development partners. In Phase 1, the interoperability champion requires an executive overview of the IMM and the roadmap process itself to successfully gain buy-in from the other executive leaders and to initiate the roadmap process by selecting key steering committee members. The steering committee itself will require details to determine the composition of the experts needed and to determine workflow during the workshops in Phase 4.

During the roadmap development phase, the IMM is expected to be leveraged to provide a baseline maturity level for interoperability. During the workshops and analysis, a target level will be established and specific action plans will be created to address any gaps to meeting the target interoperability level.

As shown in Figure 10, the process includes two types of activities—Expert judgement and consensus and Data and analysis—and six phases—1) Scoping, 2) Planning and preparation, 3) Visioning, 4) Roadmap development, 5) Roadmap implementation and revision, and 6) Assessment for application to other domains. The success of a roadmap is based on early planning and foresight, establishing a commonly "owned" vision, gaining full understanding of the national challenges and opportunities, acknowledging the importance of champions to advance the work, commitment to outcomes by both public and private stakeholders, and producing ongoing evaluation and progress reports. The development of a common vision can be informed by the desired integration vision, such as espoused in this white paper, and this provides a converging force to separate technology roadmap efforts. Champions of the work need to be recognized early on to provide effective leadership and demonstrate their passion for achieving the desired outcomes.

CLOSURE

Advancing interoperability takes foresight and upfront work on complicated issues to clarify interface points and address scalability requirements. The supporting standards and guides need to consider approaches that allow the power system (a complex system-of-systems) to evolve. Integration mechanisms need to be able to accommodate system objectives and technology solutions that will change over time. Underlying every interoperable system is hard work by many people usually clustered on specific portions of the system with business opportunities and technology expertise (ecosystems). Providing a vision of the general interoperability characteristics for future integration of devices and systems can raise awareness across ecosystems toward a common direction. With tools to measure the state of interoperability and a methodology for assessing and prioritizing gaps and challenges, roadmaps can be created by stakeholders in an ecosystem to take steps that converge toward more generally applied approaches that transcend individual ecosystems, and leverage more common approaches to support successful deployments.

This document describes a strategy to systematically pursue interoperability improvement for grid modernization and explores an application of this strategy to the timely topic of DER integration. It proposes a set of activities to bring commonality of approach to encourage convergence on agreements that apply to all the diverse types of DER technology. This involves facilitating the creation of a set of generalized grid services and identifying the performance characteristics required to provide each grid service regardless of the type of DER. By focusing on the qualifications for providing a service, the integration agreements needed should be simplified. In addition, commonality of approach to addressing interoperability gaps can lead to tools, techniques, best practices, and capabilities that can be leveraged across all types of grid-integration scenarios. Working both within and across technology communities (i.e., ecosystems) will be required to achieve the level of alignment prophesized by the vision of a modern energy grid.

As a foundation for this work, a Declaration of Interoperability was written. The declaration, which is shown on the inside back cover of this white paper, resulted from debates and revisions by all the participating DOE national laboratories and partners and was written to galvanize the community to advance interoperability for grid modernization.

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This works rests on a foundation of smart grid interoperability-related work established by the GridWise® Architecture Council over the past dozen years and by work done by the Smart Grid Interoperability Panel under the guidance of the U.S. National Institute of Standards and Technology. The vision for interoperability and plan for a strategic engagement with stakeholders follows from recent efforts funded by DOE to advance interoperability for connected buildings.

ACRONYMS

DER	distributed energy resources
DOE	U.S. Department of Energy
DR	demand response
ESI	energy services interface
EV	electric vehicle
GMLC	Grid Modernization Laboratory Consortium
GWAC	GridWise® Architecture Council
IMM	Interoperability Maturity Model
ISO	independent system operator
PV	photovoltaic

As a foundation for this work, the following **Declaration of Interoperability**, initially drafted in September 27, 2016, is the result of debates and revisions by all the participating DOE national laboratories and partners to galvanize the community to advance interoperability for grid modernization.

We, the participants in the GMLC Interoperability Program, based upon our collective resolve and industry experience, set forth these principles, enumerated below, aligned with the U.S. Department of Energy's congressionally mandated charter to convene, adopt, and deploy tools and techniques to enable interoperability to create a more reliable, secure, affordable, flexible, sustainable, and resilient electric power system. We believe this industry-led approach can, by following these principles, develop the needed solutions to achieve these goals.

We recognize that a lack of cost-effective interoperability creates onerous and ongoing problems for system integration and operation.

- *It wastes energy.* • *It wastes money.* • *It wastes time.*
- *It impedes goals of renewable generation and grid performance.*

Our future electric power system must easily integrate great numbers of an evolving mix of intelligent, interacting systems and components. Achieving this state requires the advancement of interoperability and the principles that support it; this is a shared challenge requiring alignment across all electric system stakeholders. It is therefore necessary to articulate interoperability goals and requirements and establish a strategic vision for interoperability.

Interoperability is "The ability of two or more systems or components to exchange information and to use the information that has been exchanged" (ISO/IEC/IEEE 24765). Interoperability also refers to the steps required to achieve this state, which directly relates to the level of effort to successfully integrate systems or components. With this understanding, we recognize the following principles:

- *Systems or components need to interact according to agreements at their interface boundaries.*
- *A system architecture description needs to clearly identify the interface points where systems or components may interact.*
- *Interoperability concerns need to pervade across a heterogeneous mix of technologies, business practices, and deployment approaches.*
- *Stakeholders need to participate in the process to develop, use, and maintain interoperability standards, conventions, and supporting capabilities such as certification programs, registries, and security policies.*

The principles above require changes in today's technologies, business practices, and deployment approaches, to promote interoperability and simplify the integration experiences.

We hereby recognize that improving stakeholder agreement on clear interface definitions and mechanisms to simply and cost-effectively integrate systems and components will catalyze the realization of a more efficient and secure electric system sensitive to our operational, economic, and ecologic needs. And in response, we join in the efforts to advance interoperability of the future electric system and commit to changing technologies and business processes to accomplish this mission.

Declaration of Interoperability

MORE INFORMATION

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